

Camera Ab Initio

Ravi Athale
Dennis Healy
MTO



Workshop Motivation

Sensor Electronics

1990's



2000's



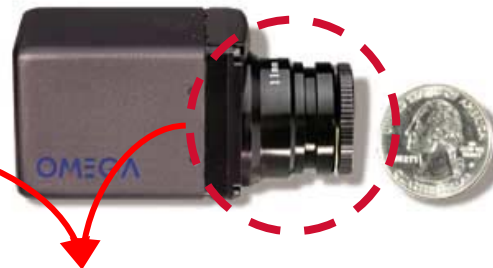
Single Chip Camera

....Moore's Law

Displays



Sensor Optics



....Maxwell's Equation

Traditional Optics:

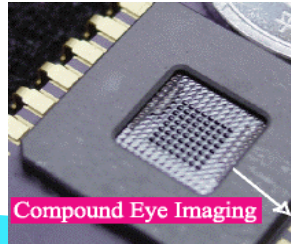
Single aperture optics performing
global processing of image formation
 $\text{Thickness} / \text{Image Size} > 1$



“Load Balancing” between Analog Optical and Digital Electronic Processing



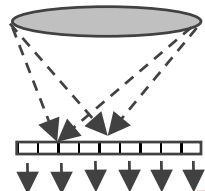
Optical Field Processing



Optical Regional Processing

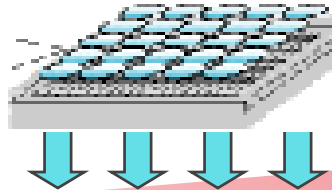


RF Pixel Sampling



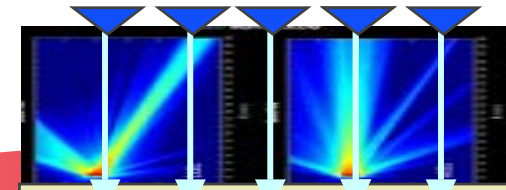
Digital Pixel Processing

Image



Digital Regional Processing

Image

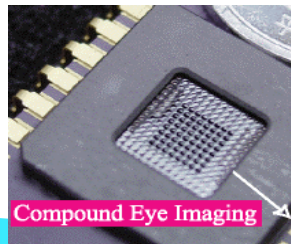


Digital Beamformer RF Array

Digital Field Processing

Image

“Load Balancing” between Analog Optical and Digital Electronic Processing



Compound Eye Imaging

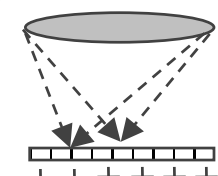


Optical Field Processing

Optical Regional Processing

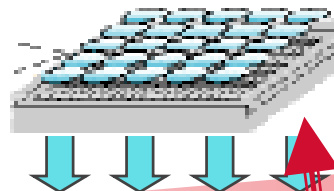
Optical Pixel Processing

RF pixel sampling



Digital Pixel Processing

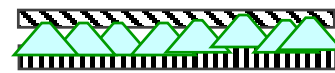
Image



Digital Regional Processing

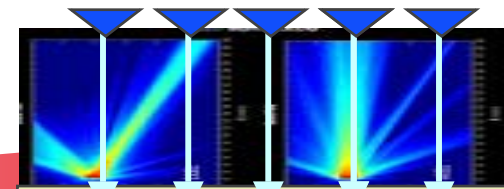
Image

Sampling Field Sensor



Digital Field Processing

Image



Digital Beamformer RF Array

Digital Field Processing

Image

Exploitation

Distribution A, Approved for
Public Release, Distribution
Unlimited

Microsystems Technology Office

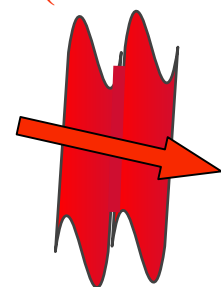
Today's Sensor Systems are feed-forward networks for transforming information in specialized stages

Physical Field
(continuum)

Digital Representation
(finite precision
finite dimensional)

Transformed
Digital Representation

Symbolic Output



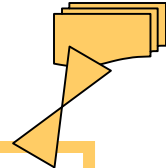
**PHYSICAL
LAYER**



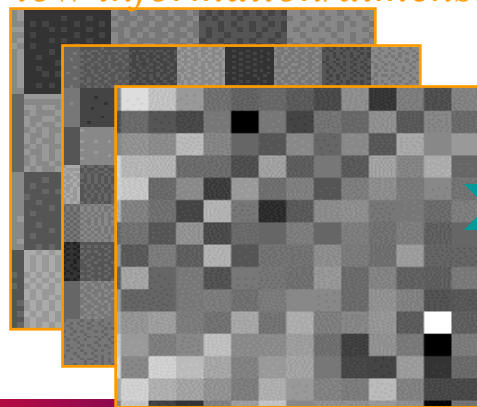
**PROCESSING
LAYER**



**EXPLOITATION
LAYER**



*Raw sensor data:
low information/dimension*



*DSP produces data reps with
higher information/dimension*

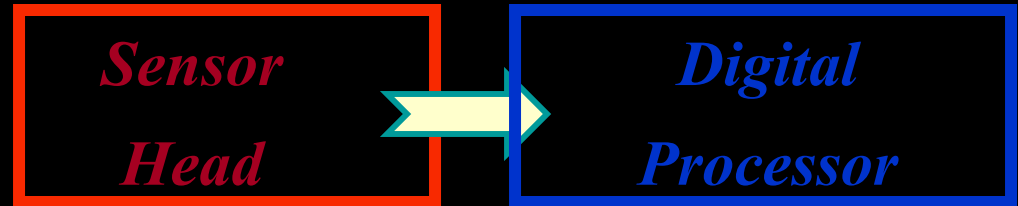


*Fast approximate
solution of a high
dimensional non linear
optimization problem*

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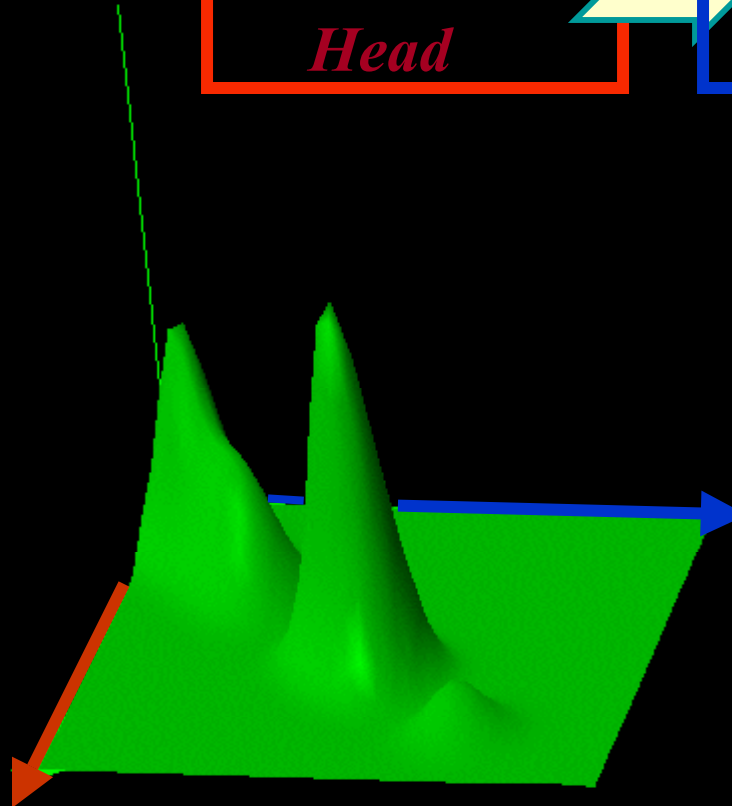
Sensor System Optimization: A cartoon



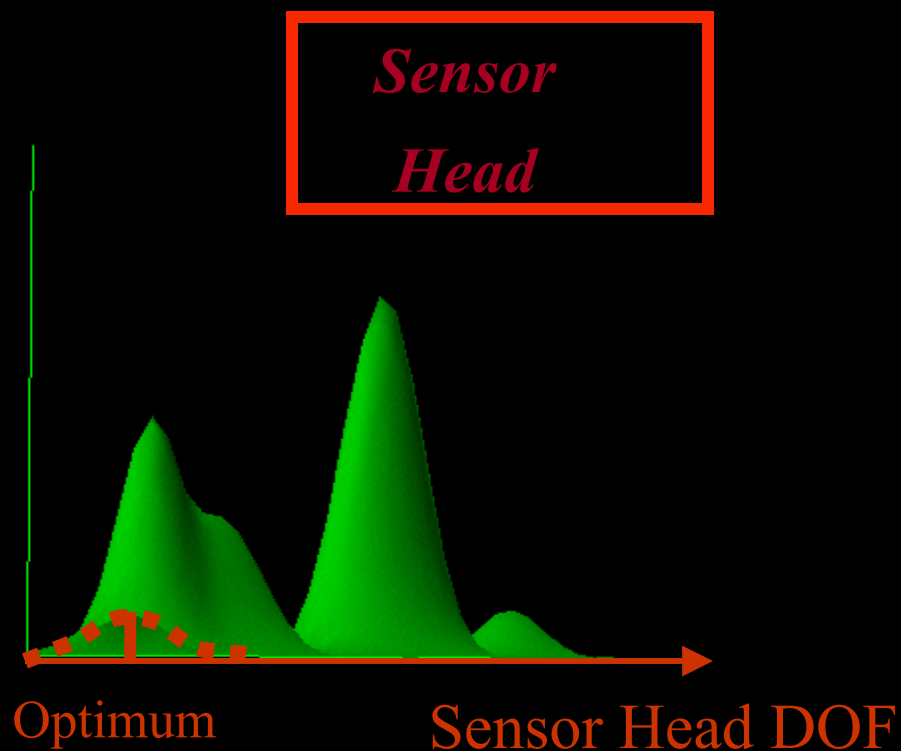
Performance Metric

DSP D.O.F.

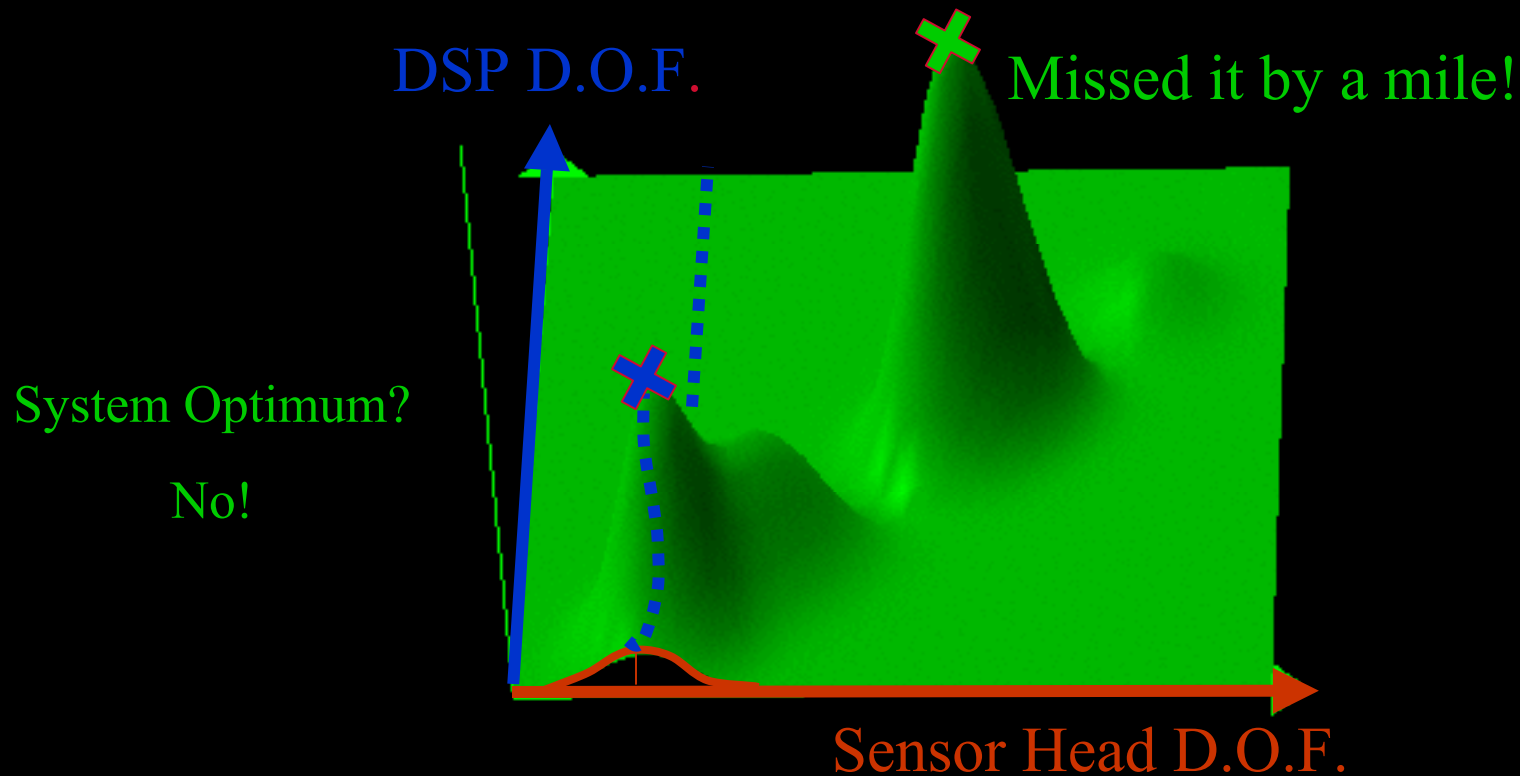
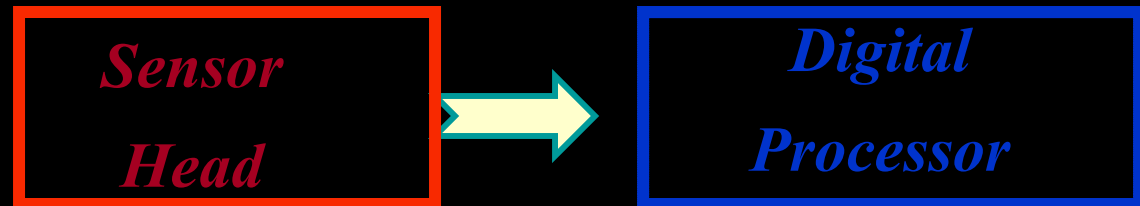
Sensor Head D.O.F.



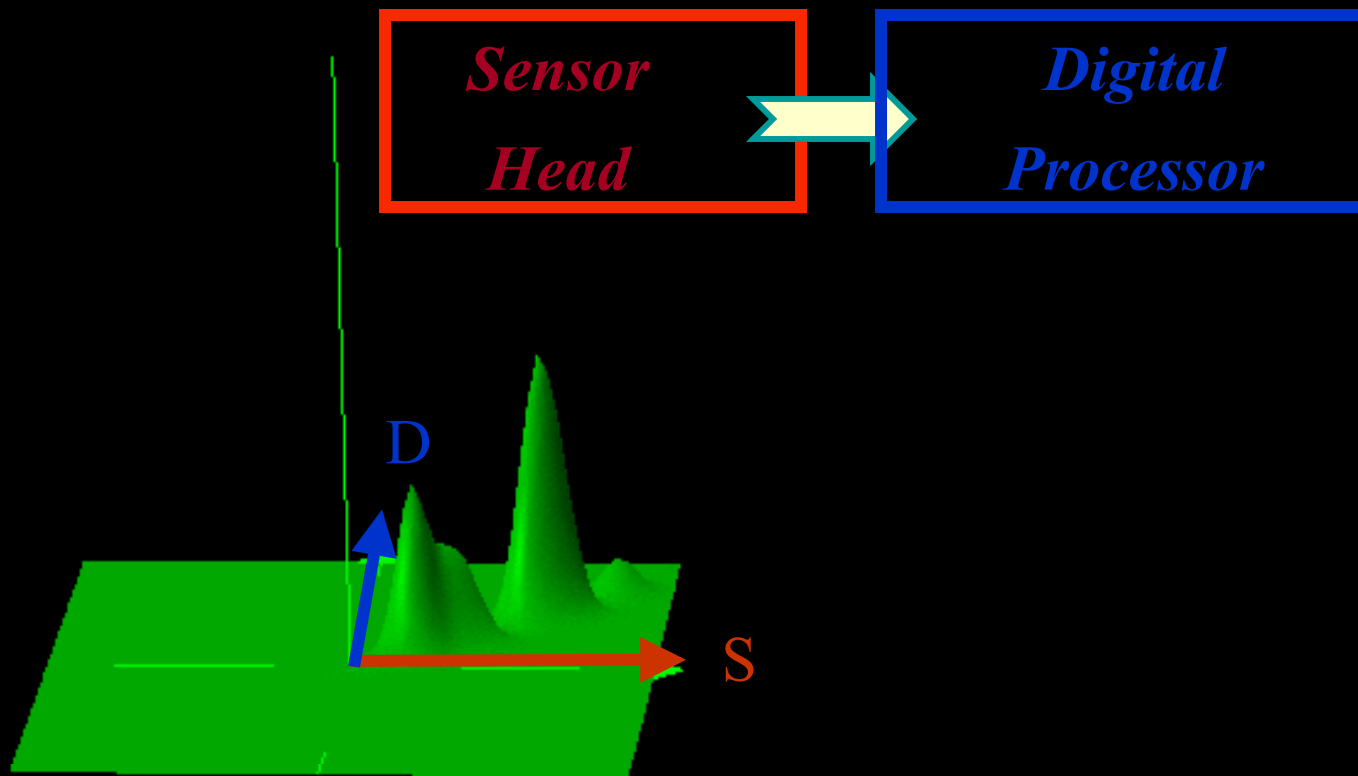
Optimize Sensor Head



Take this as initial condition for optimizing processing



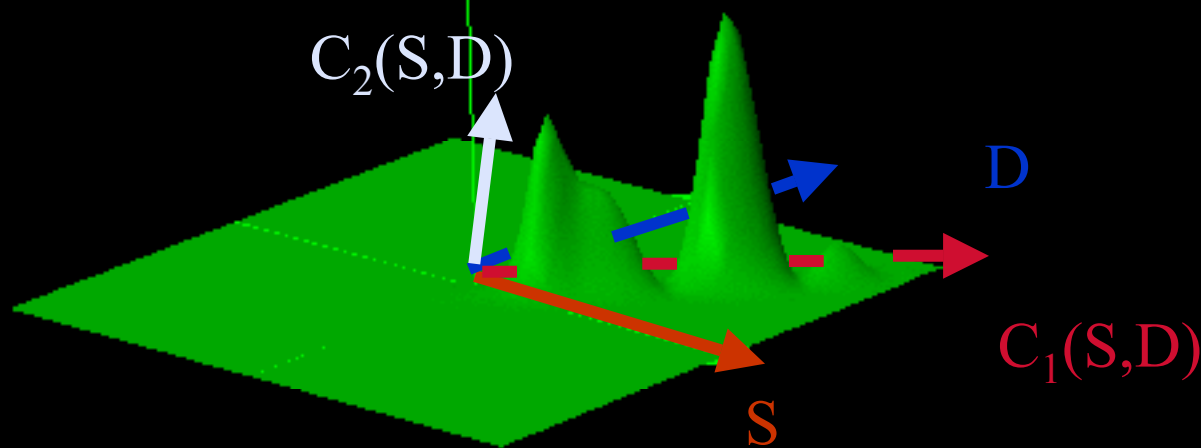
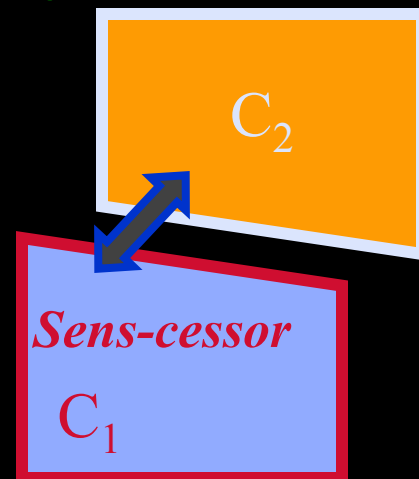
Try looking at the problem from another perspective...



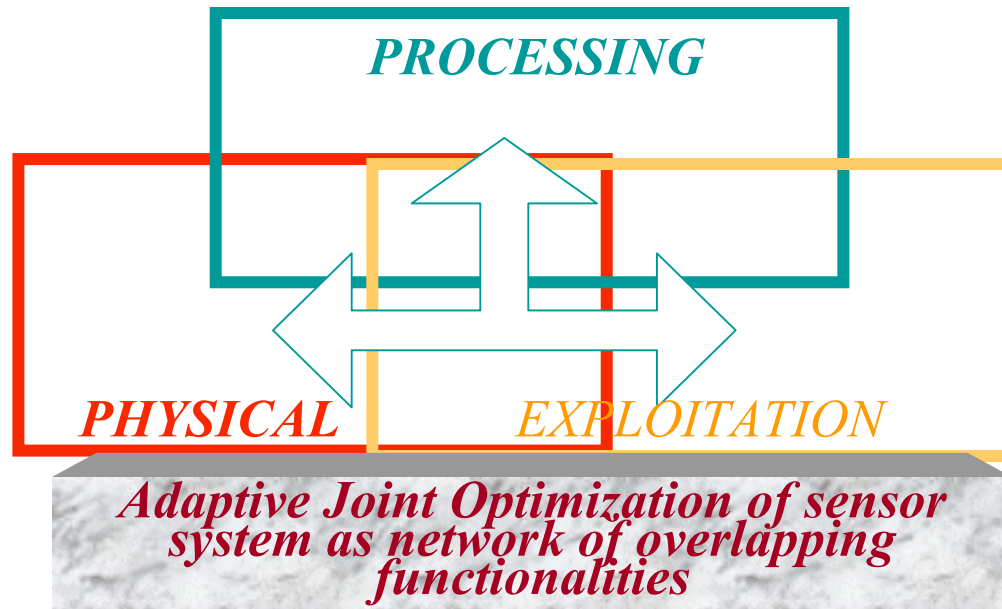
Find Coordinates appropriate to the problem structure!

Empirical Theorem:

*There often exist representations
minimizing high order interactions*



DARPA ISP PROGRAM



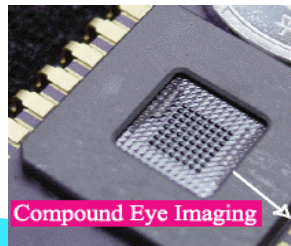
i

Components have overlapping and dynamically reconfigurable roles and full network connectivity. (LOAD BALANCING)

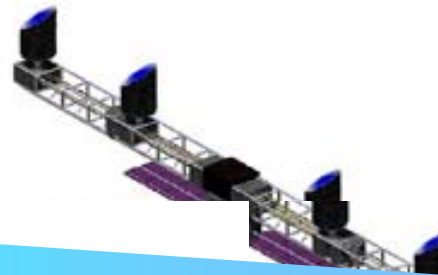
Makes “customized” measurements at physical layer under real-time feedback control from the exploitation and processing system. “20 Questions” “Information Theory Battleship”

Manages/Prioritizes data stream to affordable levels without discarding needed information

“Load Balancing” between Analog Optical and Digital Electronic Processing



Compound Eye Imaging

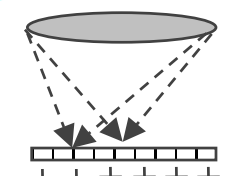


Optical Field Processing

Optical Regional Processing

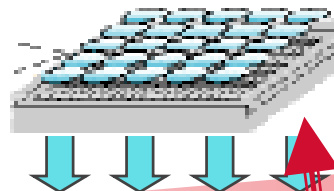
Optical Pixel Processing

RF pixel sampling



Digital Pixel Processing

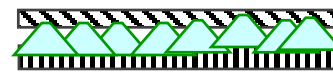
Image



Digital Regional Processing

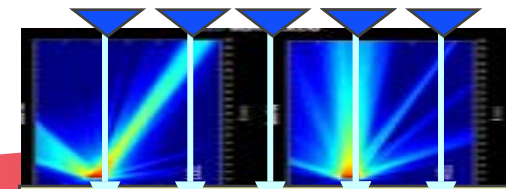
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Sampling Field Sensor



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Digital Beamformer RF Array

Digital Field Processing

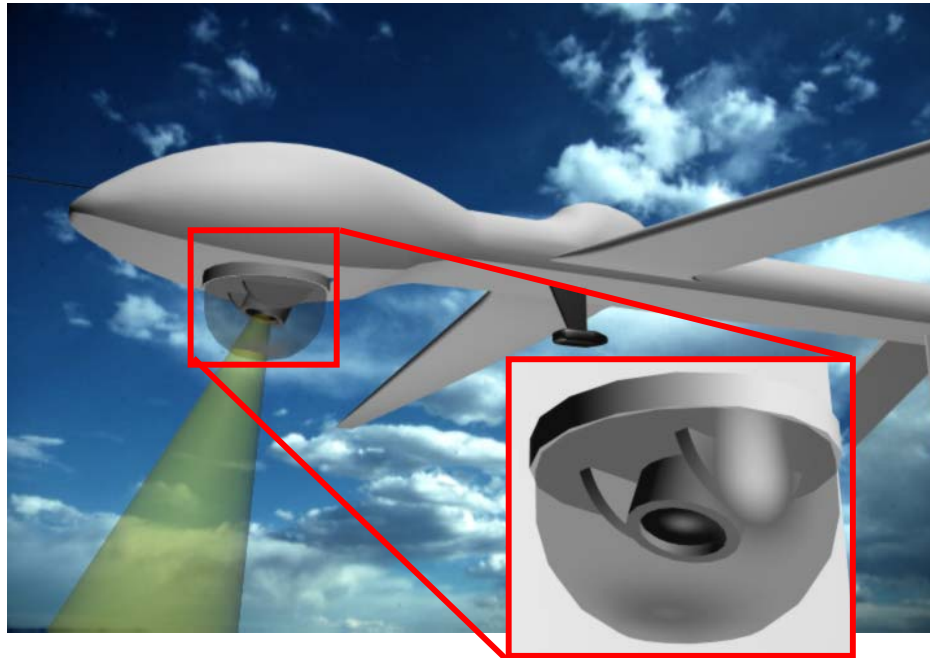
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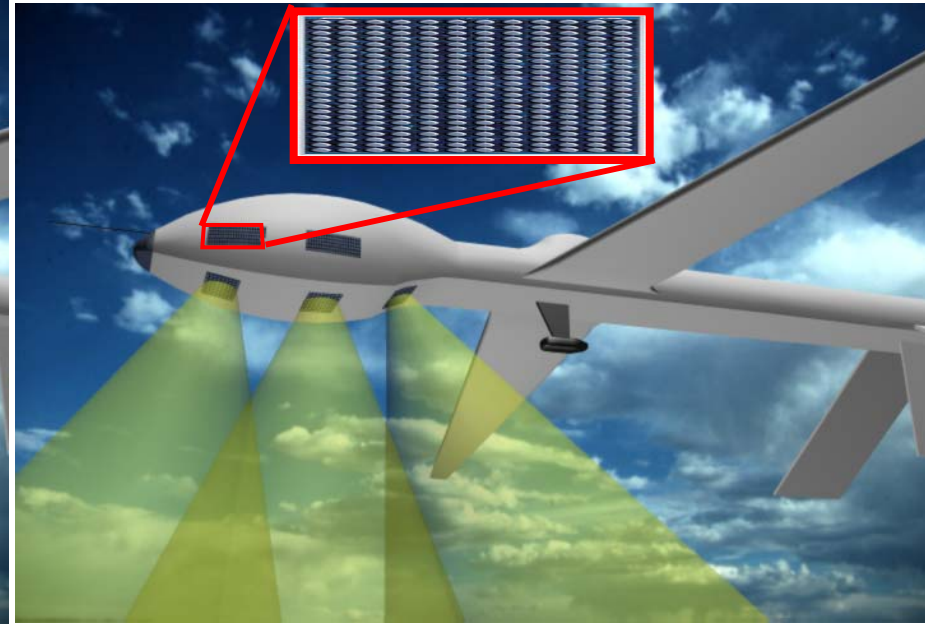
Microsystems Technology Office

Innovative Form, Fit, and Function



Now

- Single aperture
- One look => One view
- Limited scalability
- Fixed functionality



With distributed conformal imagers

- Multiple, independent apertures
- One look => Many views
- Modular extendibility
- Programmable functionality
 - Programmable zoom
 - 3-D geometric information



Morning Events

7:30 - 8:30 a.m.	<i>Registration and Continental Breakfast</i>
8:30 - 8:45 am	<i>Dennis Healy and Ravi Athale, DARPA/MTO</i>
8:45 - 9:05 am	<i>Ed Watson, AFRL</i>
9:05 - 9:15 am	<i>Joe Mait, ARL</i>
9:15 - 9:35 am	<i>Dean Scribner, NRL</i>
9:35 - 9:55 am	<i>Alan Van Nevel / Gary Hower, NAVAIR, China Lake</i>
9:55 - 10:15 am	<i>Jim Brase / Eddy Stappaerts, Lawrence Livermore</i>
10:15 - 10:45	<i>Break</i>
10:45 - 11:15 am	<i>Dave Brady, Duke University</i>
11:15 - 11:45 am	<i>Vladimir Brajovic, CMU,</i>
11:45 - 12:15 pm	<i>Steve Zucker, Yale University</i>
12:15 - 1:15	<i>Lunch</i>



Re-Imagining the Camera

- Purpose
 - Explore prospects for DARPA-style revolution in Imaging Systems
 - Determine best paths and critical steps
- Potential enablers
 - Systems Concepts
 - Materials and Meta-Materials
 - Microelectronics and MEMS
 - Advanced Mathematical Processing Algorithms
 - Advanced Exploitation Algorithms
 - Modeling and Optimization for Rapid Prototyping
- Collaborate in Blank Page conceptual design of Imagers
 - New Form/Fit/Function
 - Joint optimization/integration of Sensing, Processing, Exploitation
 - Load Balancing



Virtual Design Teams

- **Ab Initio designs**
 - **Integrated Design Teams**
 - Optics, wave processing, devices, algorithms
 - Over-riding system perspective
 - **Co-design, joint optimization of traditionally independent subsystems**
 - Eye towards end uses
 - Innovations in form, fit, function



Design Team Report/Outbrief

- **5-10 slides**
- **What is the system? (or systems)**
- **What are the new capabilities/attributes and the utility towards end use?**
- **What are the key technical challenges and what are the significant new enablers?**



These are the questions we will need to answer:

DARPA Investment Criteria

- What are you trying to accomplish?
- How is it done now & with what limitations?
- What is truly new in your approach that is likely to remove current limitations & improve performance? **Quantify this advance?**
- Why do you believe your new approach can work? What is unknown?**
- If successful, what difference will your system make and to whom?
- What are the near-term, mid-term, final exams or full scale applications required to prove your hypothesis? When will they be done?**
- What is the transition strategy?
- How much will it cost?

